WF Note- 216

Wakefield Measurements Using Low Energy Beams

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The technique for measuring wakefields by use of a drive beam bunch followed by a witness beam bunch was invented and well demonstrated at the AATF some years ago. Now, efforts by the accelerator community to design a credible NLC bring with it the need to measure wakefield effects in proposed accelerating structures to high precision.   Although SLAC's ASSET facility can, in principle, address the problem, it would be advatageous to have an inexepensive, stand alone, readily available facility based on the use of low energy beams and dedicated to those types of measurements.

In the following informally written note I describe the special considerations introduced when using low energy beams and outline an experimental procedure which promises to fulfill the requirements mentioned above.

Effects on the Witness Beam

Imagine a witness pulse as travelling through a device under study, trailing behind at some prescribed distance a relatively more intense drive pulse which has created both longitudinal as well as transverse wake fields in the device. In addition to the energy of the witness constantly changing due to the longitudinal wake, the angle and lateral offset of the pulse will also be changing due to the transverse wake.

Let's now estimate these effects using what I believe to be reasonable and applicable parameters.

Assume:

$m := 9.1 \cdot 10^{-31}$	electron mass	[Kg]
$q := 1.6 \cdot 10^{-19}$	electron charge	[Coul]
$L := 1$	section length	[m]
$E := 200$	transverse wake field	[V/m]
$c := 3 \cdot 10^{8}$	speed of light	[m/s]
$\gamma_{start} := 10$	incomingwitness gamma	
$\beta := 1$	close enough for government work (can't believe I said that!)	

Let's say that the longitudinal wake causes the witness pulse to emerge from the section at an energy defined by γ_{end} as an example. (γ_{end} can be greater or less than γ_{start})

$$\gamma_{end} := 8$$

so the rate of gamma change along the trajectory is

$$R := \frac{\gamma_{start} - \gamma_{end}}{L}$$

The angle and position of the witness trajectory as it exits the test device is given as follows:

Define

$$\eta(s) := \frac{q}{c^2 \cdot m \cdot \beta} \cdot \int_0^s \frac{1}{\gamma_{start} - s \cdot R}\, ds$$

$$\zeta(s) := \int_0^s \eta(s)\, ds$$

For the parameters given earlier, the exit angle θ and offset y_{exit} would be

$\theta := \eta(L) \cdot E$ or $\theta = 4.359 \times 10^{-5}$

and

$y_{exit} := \zeta(L) \cdot E$ or $y_{exit} = 2.099 \times 10^{-5}$ (yep, they're small numbers, but wait!)

<u>How a Measurement Could be Performed</u>

I'll now describe a basic experimetal arrangement and outline how data from it could be analyzed.

Assume that the drive and witness beams have been adjusted so that they are co-linear in the absence of wake deflections. Now assume that the test device is displaced vertically by some small amount (to excite deflecting mode(s)) and that the witness is placed behind the drive pulse some known distance.

Upon exiting the test device, allow the beams to drift a short distance (e.g. 20 cm) before encountering a horizontal bending magnet that bend both beams enough that the drive beam can be separated and "dumped". The witness beam is then allowed to drift a longer distance (e.g. 1.5 to 2 m) where it encounters a beam position monitor (BPM) where its vertical position can me determined.

I propose that it will be highly advantageous to use a "center null" type device, where both X and Y positions are defined where corresponding output signals are "zero". This could be, for example, made of small Faraday Cup segments or even secondary emission foils. (This may be detailed in a later note.)

For now, assume that the BPM can be moved vertically to detect "null" and that it's position be carefully measured (Note- micropositioners are readilly available that can do this)

The procedure is to:

1. Adjust the horizontal bend to center the beam horizontally on the BPM. From this, one finds γ_{end}

2. Now position the BPM vertically to detect the vertical offset caused by the wake fields.

3. If the total drift distance from the end of the test section to the BPM is defined as D, the deflecting E-field inside the device under test can be obtained from:

$$E := \frac{\delta y}{\zeta(L) + \eta(L) \cdot D}$$

where δy is the measured vertical beam displacement at the BPM

Note that I ignore possible vertical focussing in the bend magnet because the bend angle that is set to achieve a horizontal "zero" at the BPM has normal entrance and exit edge angles, the magnet gap is small, and the bend radius is assumed "large". In other words, negligable vertical focussing.

Let's do this the other way and see if a 200 V/m field in a 1 m long test devices and the beam energies suggested above would lead to useful results. Let drift D be 2 m.

$$\delta y := E \cdot (\zeta(L) + \eta(L) \cdot 2) \quad \text{or} \quad \delta y = 1.082 \times 10^{-4}$$

(Not bad, if the beam spot is small)

How large might the beam spot be? Assume the witness beam normalized emittance is 0.1 mm-mrad (J. Power's info). Also assume that the witness beam is at a vertical waist with β = 2 m as it exits the test device. At the BPM, located about 2 m downstream, the spot size with have an rms height of about

$$h_{rms} := 2\sqrt{\frac{4 \cdot 10^{-7}}{\gamma_{start}}} \quad \text{or} \quad h_{rms} = 4 \times 10^{-4}$$

[m]

I believe that "zeroing type" BPM can resolve a null to about 1/10 the rms beam size. This may require a averaging over several pulses depending upon the stability of parameters. Thus in this example, the resolution is about 4 X 10^{-5} [m] , a value less than δy (see above). Good!

An alternative to physically moving the BPM is to place a weak vertical bend magnet near the BPM and measure the field required to obtain "zero". While perhaps this simplifies the apparatus, it does not change the expected accuracy of the measurement..

Summary

I have analyzed wake field effects on a low energy witness beam where accumulating energy and deflections cannot be ignored, and have outlined a technique by which those effects can be measured with high precision in a relatively simple way. A specific, more optimized design proposal is forthcoming.